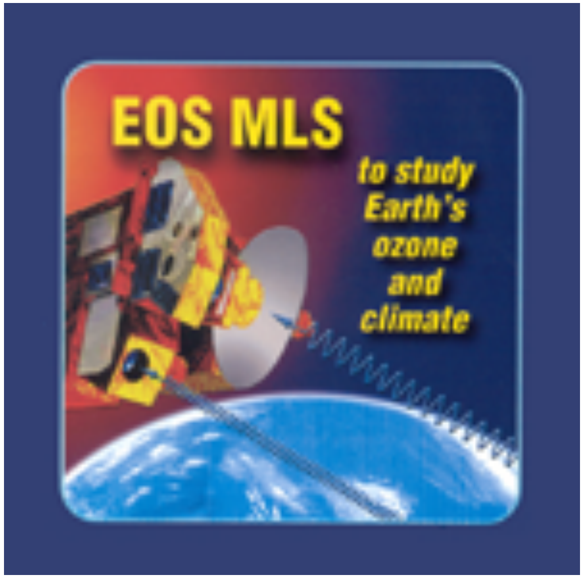
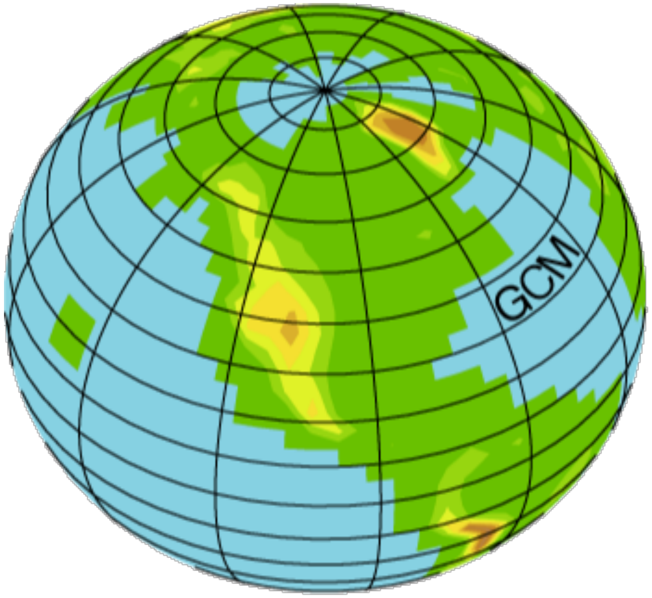
Role of Stratospheric Water Vapor in Global Warming from GCM Simulations Constrained by Observation





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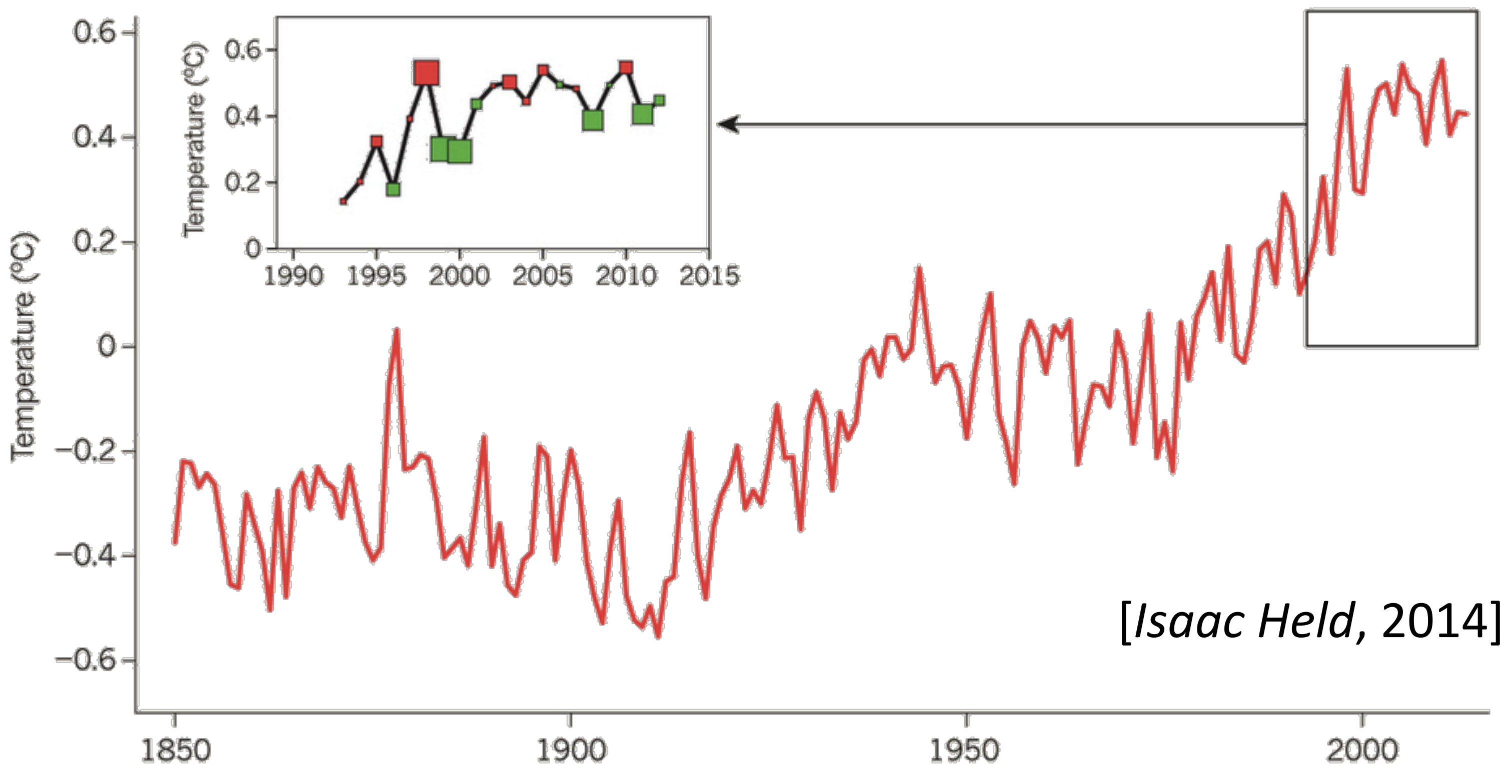
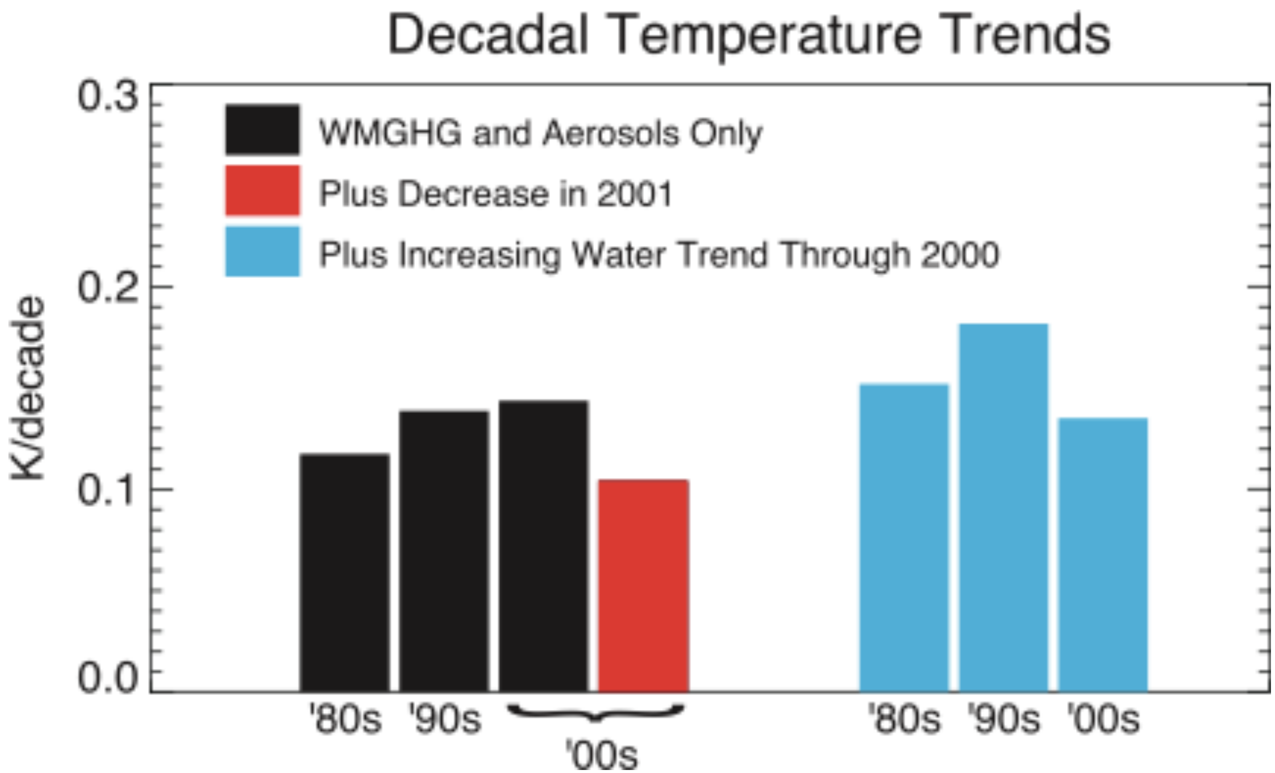
Global warming – "the biggest mystery in Climate Science"



- Global surface temperature arises 0.5 C from 1970-2000.
- Hiatus of global warming has occurred since 2000.
- Forcing agents VS. internal variation?

Motivations

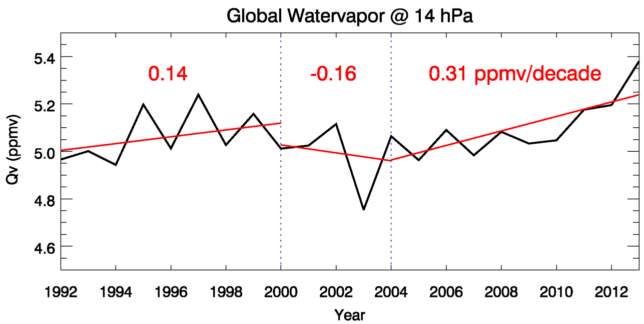
- Water vapor has a great potential to modulate global climate by altering the inferred opacity of the atmosphere. In particular, Stratospheric water vapor (SWV) provides about +0.3 W/(m^2•K) climate feedback to the global warming [*Dessler et al.*, 2013].
- *Solomon et al.* [2010] suggested SWV acted to enhance the global warming by 30% during 1990s and slow the rate of global warming by 25% after 2000.

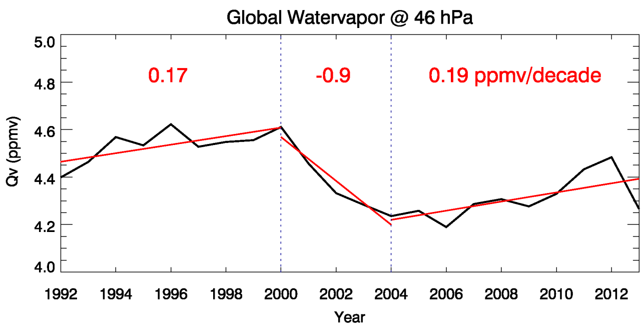


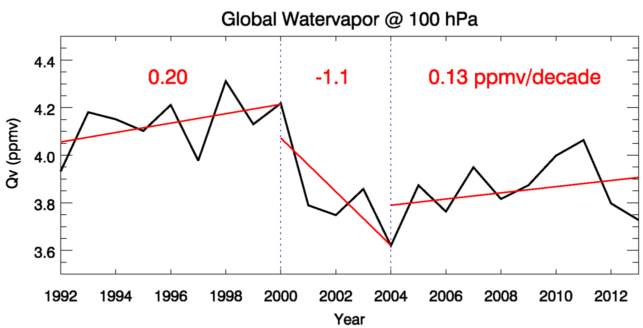
[*Solomon*, 2010]

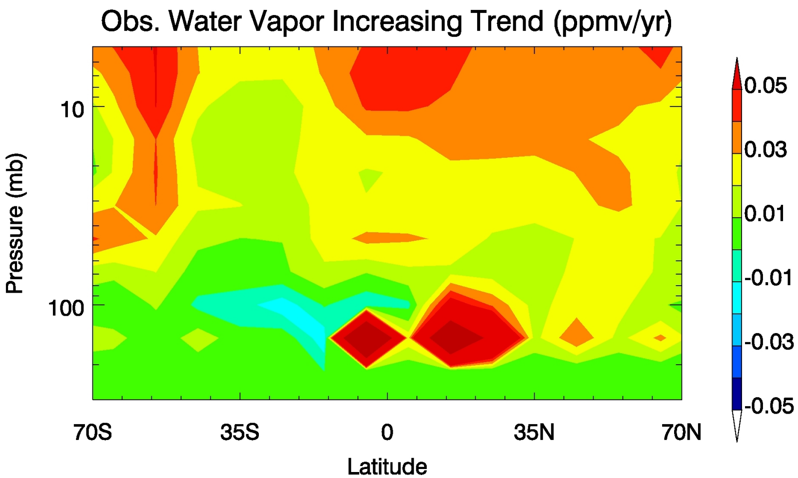
Historic trends of SWV from GOZCARDS

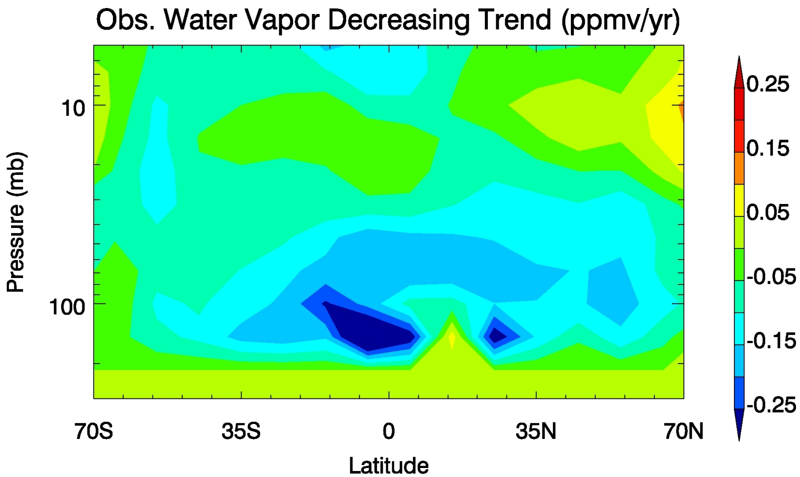
- The GOZCARDS data set is compiled by high quality satellite data form past missions (e.g. SAGE, HALOE) as well as ongoing missions (ACE-TFS and Aura MLS) [*Froidevaux*, 2014, submitted].









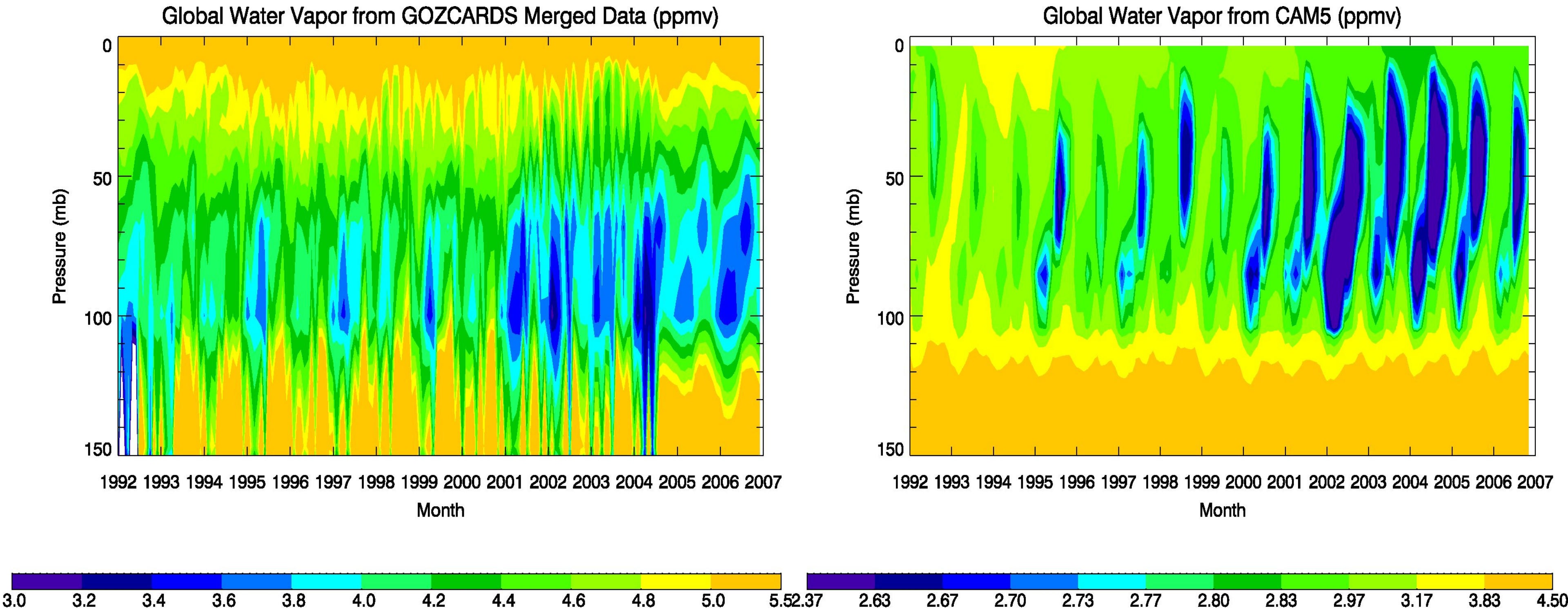


Methodology

- AMIP type (prescribed SST) simulations to examine the interannual variation of stratospheric water vapor (SWV) and the influences from external forcings.
- Atmosphere-Slab Ocean coupled simulations to quantify the contribution of SWV to the global warming.
    - Equilibrium response to certain SWV perturbation
    - Transient response to observed SWV trend

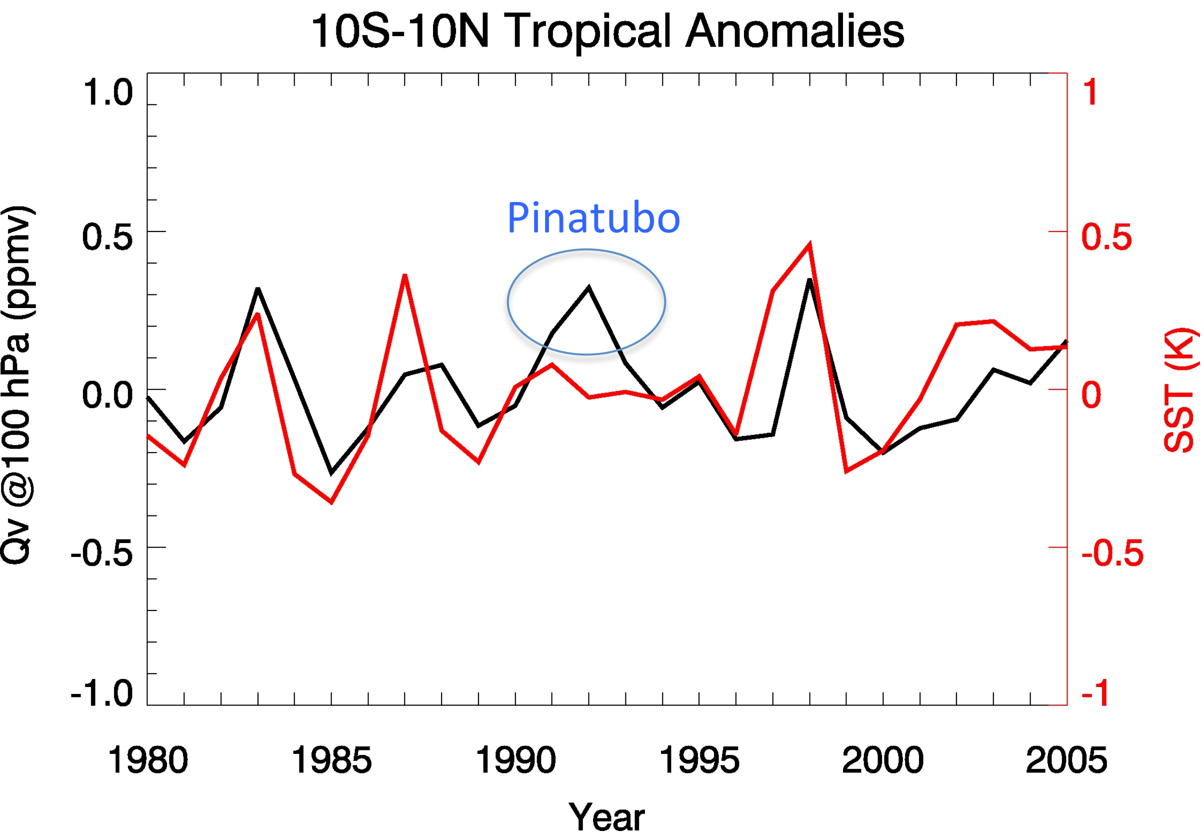
Simulation Tool	NCAR CESM 1.2.1 (CAM5.2)
Resolution	$1.9^{o} \times 2.5^{o} \times 30$ (10 levels in stratosphere)
Initial Condition and Forcings	Year 2000 scenario
Chemistry	Not included
CH_4 concentration	1.76 ppmv (fixed)

Interannual Variation from AMIP-type Simulation



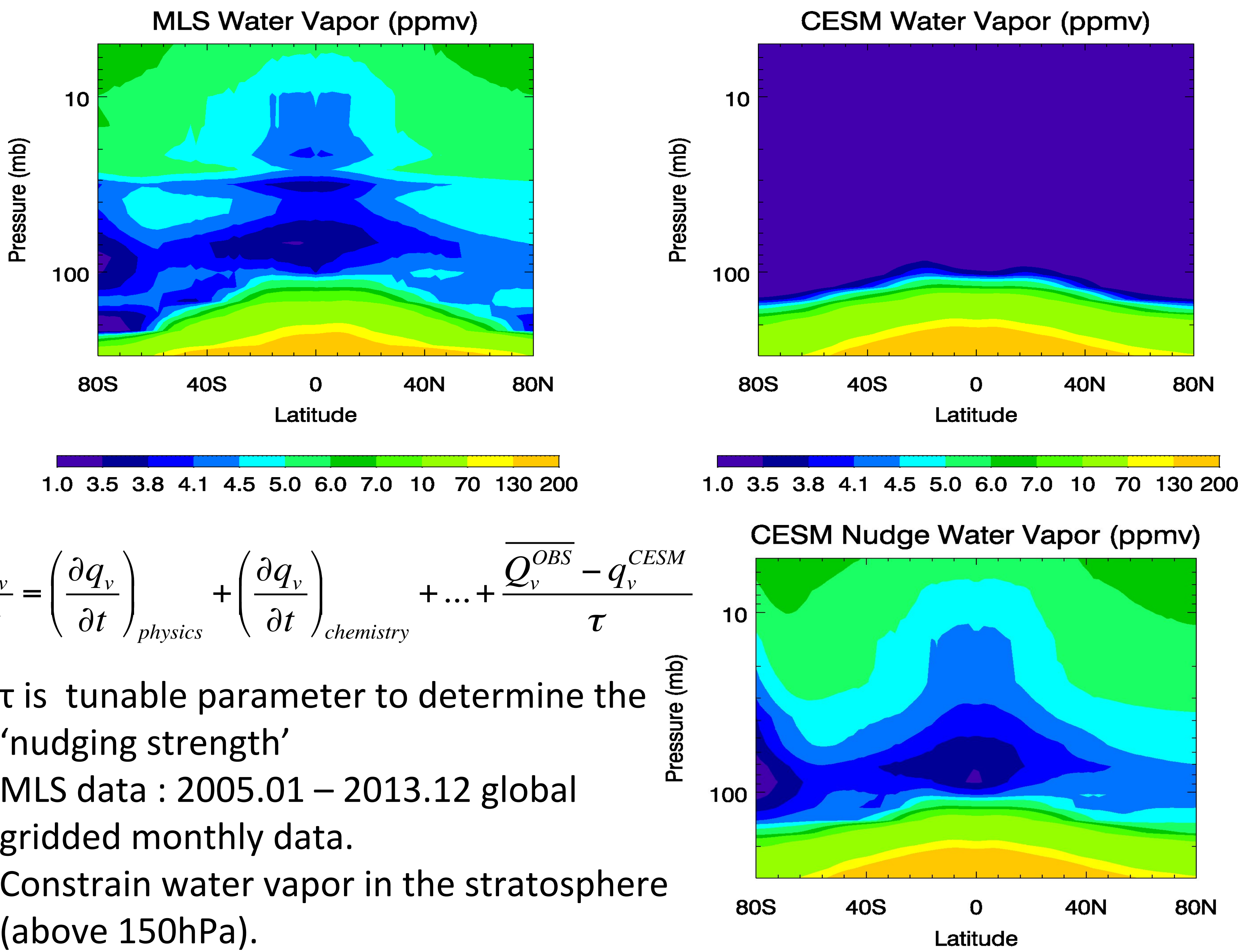
- Signals of Pinatubo (1991) are consistent between Obs. And CAM5 simulations.
- Model predicts a similar drop of H_2O in lower stratosphere after 2000.
- Overall magnitude of stratospheric H_2O amount from CAM5 is lower than obs.
- Much less H_2O in stratosphere from CAM5 may be attributed to unresolved transport of water vapor in UTLS and stratospheric dynamics.
- Observed seasonal variations are noisy before Aura MLS (2004).

Impacts of SST on Stratospheric Water Vapor



Lag	Correlation
-4	-0.06
-3	-0.26
-2	-0.27
-1	0.45
0	**0.65**
1	-0.37
2	-0.36
3	0.05
4	0.10

Correct SWV climatology in model : Nudging approach



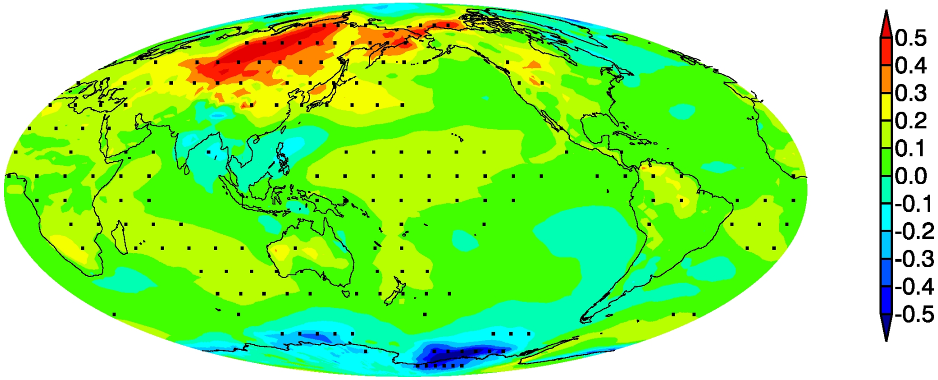
$$\frac{\partial q_v}{\partial t} = \left(\frac{\partial q_v}{\partial t}\right)_{physics} + \left(\frac{\partial q_v}{\partial t}\right)_{chemistry} + \ldots + \frac{\overline{Q_v^{OBS}} - q_v^{CESM}}{\tau}$$

- τ is tunable parameter to determine the 'nudging strength'
- MLS data : 2005.01 – 2013.12 global gridded monthly data.
- Constrain water vapor in the stratosphere (above 150hPa).

Equilibrium Response to SWV Perturbation

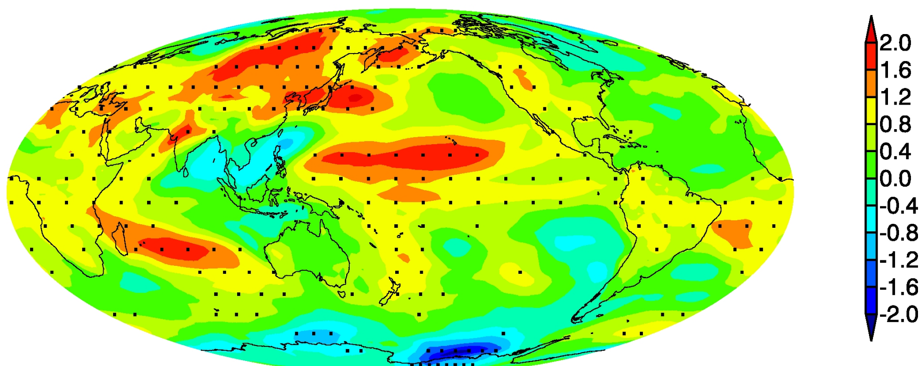
+ 1 ppmv SWV

Surface Temperature Difference (K)



Global mean = 0.075 K

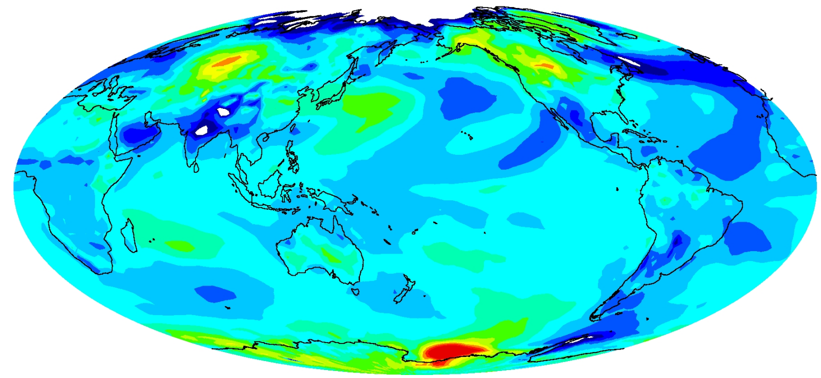
Clearsky Downwelling Surf. Longwave Flux Difference (W/m^2)



Global mean = 0.56 W/m^2

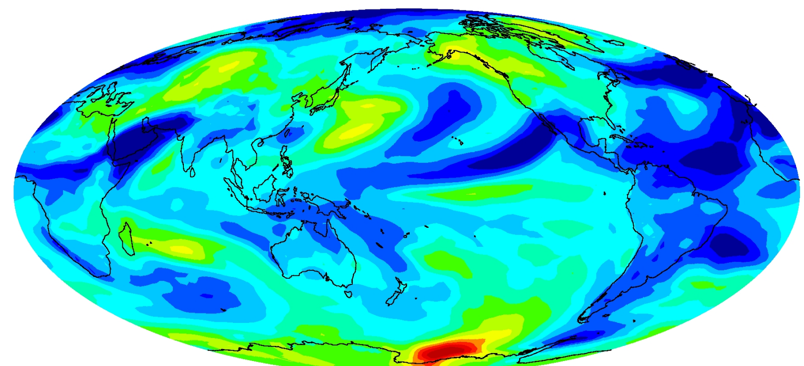
– 0.5 ppmv SWV

Surface Temperature Difference (K)



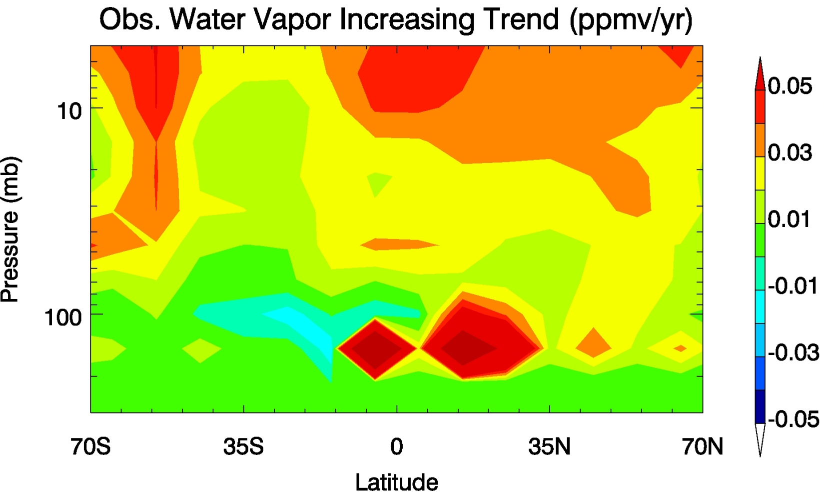
Global mean = -0.065 K

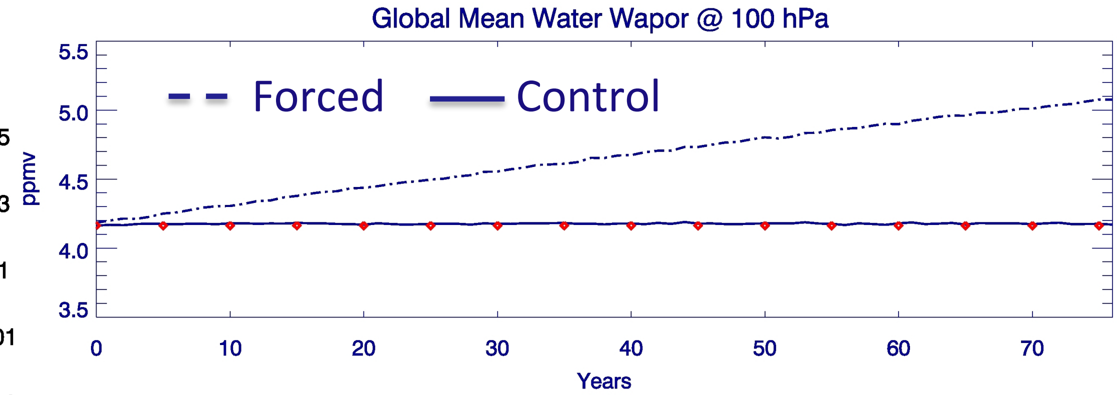
Clearsky Downwelling Surf. Longwave Flux Difference (W/m^2)



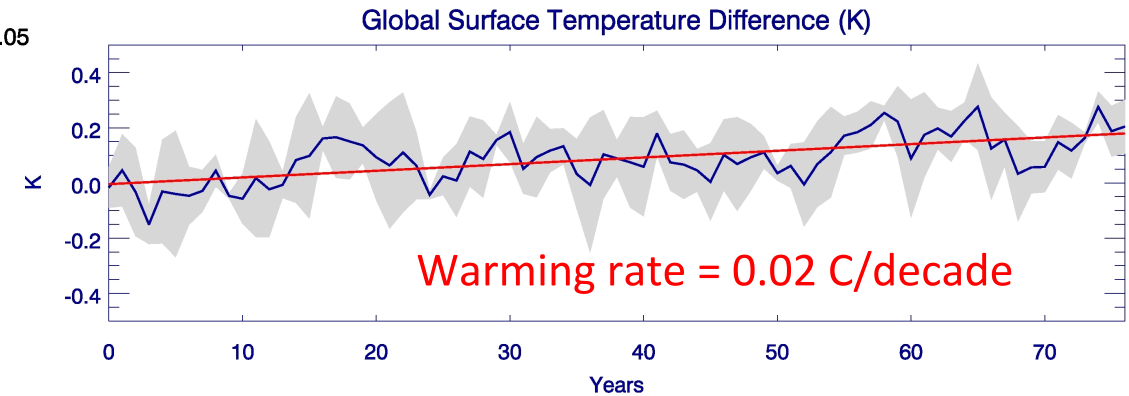
Global mean = -0.43 W/m^2

Transient response to SWV increase

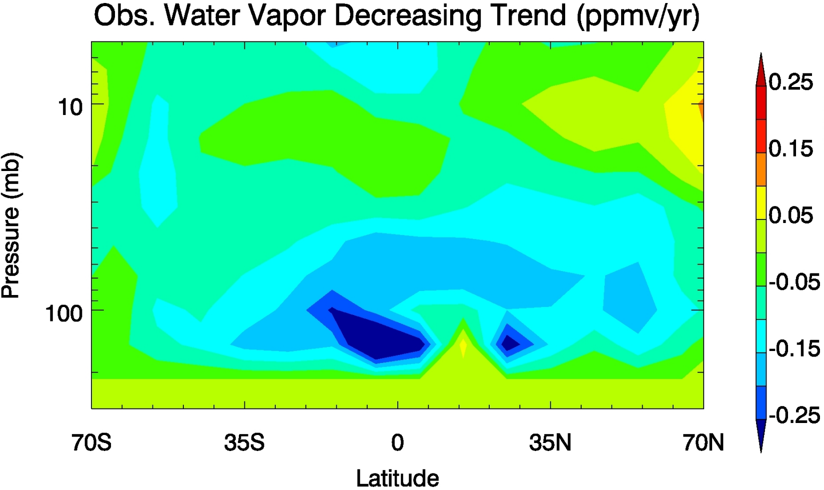




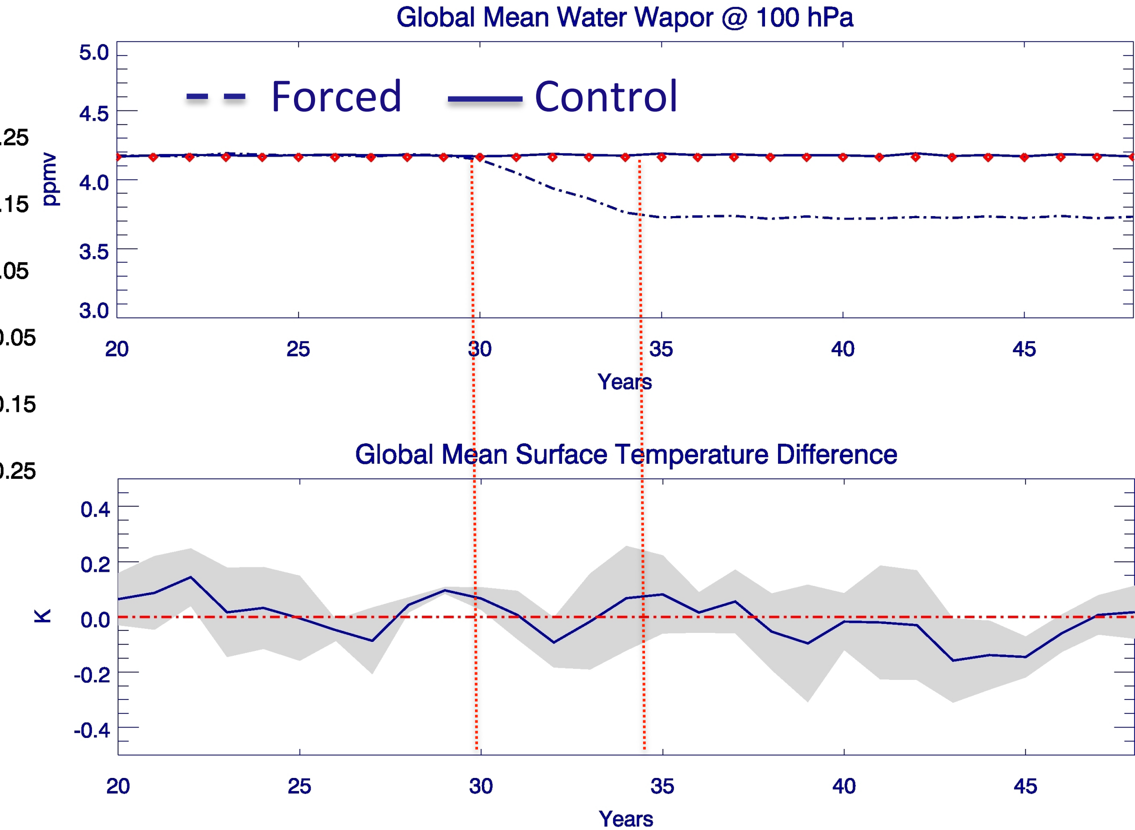
Observed SWV trend averaged between 1992-2000 and 2004-2012



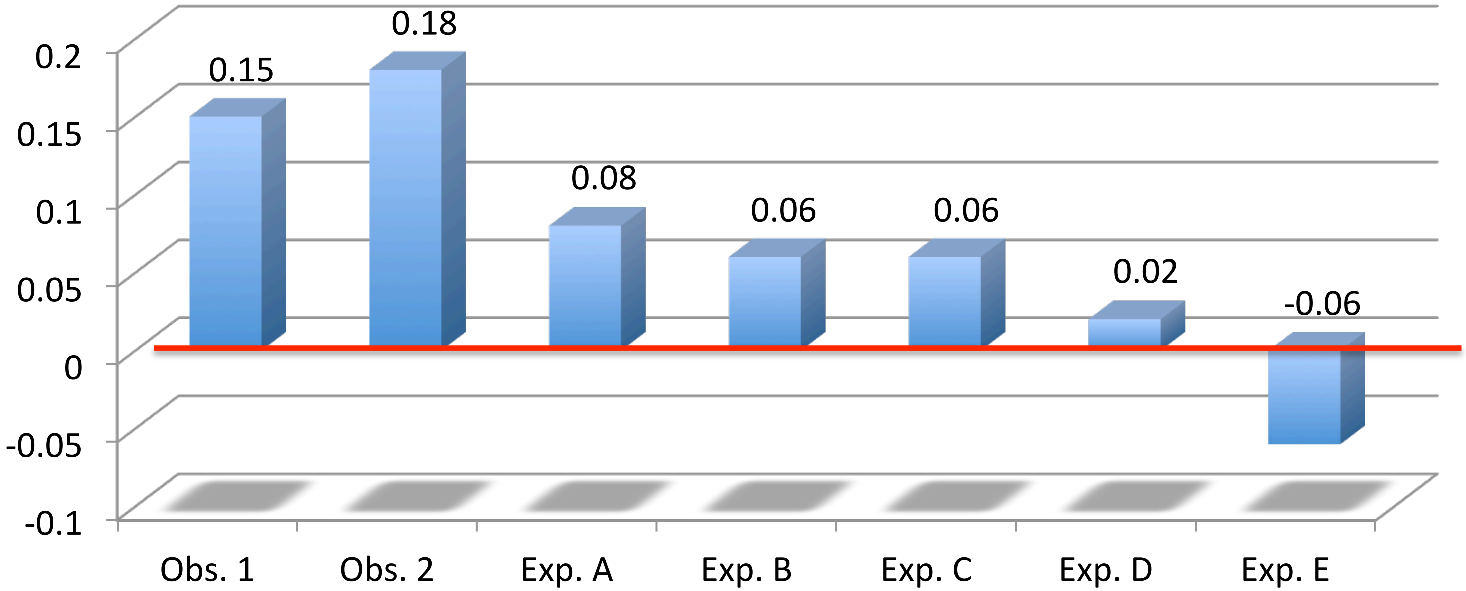
Transient response to SWV decrease



Observed SWV trend from 2000-2004



Response of Surface Temperature: Obs. Vs. Model



Relative Change of Surface Temperature (K)

Obs. 1	Observed decadal change from 1980-1990
Obs. 2	Observed decadal change from 1990-2000
Exp. A	Perturbed by 1 ppmv
Exp. B	Perturbed by 1 ppmv (only at 100 hPa)
Exp. C	Perturbed by 1 ppmv (only tropics)
Exp. D	Decadal change from transient simulations
Exp. E	Perturbed by -0.5 ppmv

Conclusions

- With prescribed external forcing, interannual variation of stratospheric H_2O (SWV) can be reproduced and the 'instantaneous' influence of SST on SWV can be identified over tropic.
- Amount of SWV simulated by CESM is significantly lower than observation. A nudging approach is developed.
- Constrained by MLS observation, elevation of SWV by 1 ppmv produces a robust surface warming about 0.08°C globally after reaching an equilibrium climate (about 25% of the observed warming from 1980-2000). Decrease of SWV by 0.5 ppmv causes -0.06°C surface cooling.
- By imposing an observed increasing rate of SWV (from 1992-2000), AOGCM predicts a slow surface warming about 0.02°C/decade, whereas there is no significant surface response to the sudden drop of SWV during 2000 to 2004 in the simulations.
- Our modeling study suggest SWV contributes positively to the global warming in the decadal time scale. The abrupt drop of SWV couldn't explain the simultaneous warming hiatus after 2000.

Evaluation of the Coupled Model